PHYSICS OF A TOTAL ENERGY VARIOMETER

The following paper uses basic physics to explain how a TE (Total Energy) variometer works. As you read through this paper, remember that a Total Energy (TE) variometer is an instrument that measures CHANGE in energy. The rate of change in energy is defined as power. Therefore, in its simplest form, a variometer can be considered a power meter.

Let's start by defining total energy. Total Energy is the sum of the potential energy (E_P) and kinetic energy (E_K). Potential energy is a dependent on altitude, and kinetic energy is a function of speed.

(1) $E_T = E_P + E_K$

The first step in calculating total energy is to expand the E_P and E_K terms (see Eq. 2). The potential energy is a function of altitude (h), mass (m) and gravitational acceleration (g). The kinetic energy is a function of mass (m) and velocity (v).

(2) $E_T = mgh + (1/2)mv^2$

Admittedly, a little magic goes on in this next step (Eq. 3). Surprisingly, TE (Total Energy) variometers never require the user to enter the mass (weight) of the glider – the weight and model of the glider are not important in TE calculation. The same TE variometer for a 21-meter super ship will also work in the 2-33 (also a super ship of sorts). Did you ever wonder why? Mathematically (and with some liberal hand waving in my explanation), the total energy (ET) is converted to potential height by dividing both sides the equation by the factor mg (Eq. 3). Yes, it's sort of magical, but it's algebra.

(3) $E_T/mg = h + (1/2)v^2/g$

After dividing by mg notice that the E_P (formerly mgh), now simply becomes h. For consistency of units, all energies have been reduced to a potential height. In other words, we've eliminated mass (m) from the right side of the energy equation. This explains why we never setup the TE variometer with a mass parameter. Okay (I hear some of you), the mass is entered into some variometers, but this is only used to calculate minimum drag, best L/D, netto, STF (speed-to-fly), etc. The mass is not part of the basic TE equation or displayed value.

At this point, it's key to recognize that we're still manipulating the total energy equation and not a power equation. However, a TE variometer is actually measuring a rate of change in total energy, which is power. Therefore, it's necessary to divide the entire equation by some time interval, T, to calculate a rate of energy change. Reemphasizing, a TE variometer is measuring the rate of change (positive or negative) of the total energy. In Equation 4, both sides of TE equation have been divided by the time interval, T. This provides a rate of change in TE.

(4) TE Variometer Reading = $(h-h_0)/T + [\ (1/2)(v-v_0)^2/g]/T$,

v0 is the starting velocity and v is the velocity at the end of the time T.

h0 is the starting altitude and h is the altitude at end of time T

Simplifying further,

(5) TE Variometer Reading = Actual Rate of Climb + ½ $[(v-v_0)^2/g]/T$

Equation 5 is the key to understanding a TE variometer. It explains why a TE variometer behaves the way it does. The rate of energy change is measured as the sum of the change in altitude and the change in kinetic energy. The units for the TE reading are climb or descent rate, for example knots or feet per minute. The units for the original kinetic energy side of the equation also reduces to a climb or descent rate – this shows that the units are conserved.

One thing needs to be pointed out. If Glider A and Glider B have the same TE variometer reading (e.g., up 4 knots), but Glider B is twice as heavy as Glider A, then Glider B is experiencing double the rate of energy change as Glider A.

Let's look at specific scenarios and relate back to Equation 5.

<u>GLIDER IS OPERATING IN STILL AIR and SPEED REMAINS CONSTANT</u>: The TE variometer should read actual descent rate of the glider. (v-v0) is zero, therefore TE Variometer Reading = Actual Rate of Climb (or Descent).

<u>GLIDER ENCOUNTERS A THERMAL and SPEED REMAINS CONSTANT</u>: The TE variometer should read actual climb rate (provided the thermal is stable, there's no change in airspeed and the glider is experiencing 1g).

<u>GLIDER IS OPERATING IN STABLE AIR and PILOT PULLS BACK ON THE STICK</u>: Initially, the glider is experiences more than 1g acceleration. In this scenario, the pilot is trading speed for altitude. However, notice that increasing g (the acceleration of gravity) in Equation 5 has the effect of reducing the E_K. The initial movement of the TE variometer pointer will be slightly downward due to increased g force. After the climb is stabilized, the TE variometer will read zero. This same phenomenon occurs when pulling up into a thermal – there is often an initial downward movement of the TE variometer pointer.

<u>GLIDER IS OPERATING IN STABLE AIR and PILOT PUSHES FORWARD ON THE STICK</u>: This is the opposite scenario to the pulling back on the stick. In this scenario, the glider initially experiences less than 1g. As a result, the TE variometer pointer will initially swing slightly upward then stabilize to zero.

<u>GLIDER ENCOUNTERS A STRONG CLOUD STREET, HOLDS ALTITUDE and ACCELERATES to a HIGHER SPEED</u>: During the initial acceleration, the TE variometer will read a climb (although the glider is not climbing). Remember, a TE variometer is measuring a change in energy, but

the rate of energy change is calibrated in rate of climb (or descent). In this case, kinetic energy is increasing. Once the airspeed stabilizes, the TE variometer pointer should stabilize at zero (when neither the altitude nor airspeed are changing).

FINAL THOUGHT: This summary is incomplete. As usual, real life is always more complicated. For example, TE probes are not perfect. Flight polars might take on peculiar shapes due to flaps or changes in airflow. Some variometers make use of accelerometers and can compensate for g forces. Smoothing of pressure sensors is another factor that varies among different configurations. There are a handful of factors that make this summary less than 100%. However, the basic physics can be used to better understand the principles behind a TE variometer.

Bob